REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 1/24/03	3. REPORT TYPE AND DATES COVERED 01/Sep/98 Final Report 08/31/02

4. TITLE AND SUBTITLE

Design and performance analysis of multicarrier CDMA systems.

5. FUNDING NUMBERS

DAAG55-98-1-0473

6. AUTHOR(S)

Laurence B. Milstein

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of California, San Diego
9500 Gilman Drive
La Jolla CA 92093-0407

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U. S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

37582.9-CI

11. SUPPLEMENTARY NOTES
   The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT

   Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

   The research being conducted is designed to yield major improvements in the capabilities of military wireless communications systems. The new system is designed around a physical layer based upon a wideband direct sequence (DS) multicarrier (MC) code division multiple access (CDMA) link. Among other things, an MC signal does not require a contiguous spectrum; this means, for example, that an MC CDMA network can be overlaid upon an existing set of narrowband signals simply by leaving appropriate gaps in the placement of the multiple carriers. Such a characteristic will allow the military to employ the same frequencies as used by various commercial systems, thereby making use of the technology advancements in those frequency bands, and yet not be limited in deployment because of excessive interference from conventional narrowband signals. We have emphasized the effect of estimation errors in determining channel state information for use in optimal receiver design for MC CDMA systems, and have performed analyses of performance, as measured by the average probability of error of the system. We have also included the use of space-time spreading.

20030326 060

14. SUBJECT TERMS

   CDMA, multiple access interference suppression.

15. NUMBER OF PAGES

4

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. 239-18
298-102

REPORT DOCUMENTATION PAGE
(Continuation Sheet)

1a.   Manuscripts submitted, but not published:

L. L. Chong and L. B. Milstein, "The effects of channel estimation errors on a space-time spreading CDMA system with dual transmit and dual receive diversity." Submitted to *IEEE Transactions on Communications*.

1b.   Papers published in peer-reviewed journals:

L. B. Milstein, "Wideband code division multiple access,"*IEEE Journal on Selected Areas in Communications*, vol. 18, no. 8, pp. 1344-1354, August 2000. (Invited paper)

L. Fang and L. B. Milstein, "Successive interference cancellation in multicarrier DS/CDMA," *IEEE Transactions on Communications*, vol. 49, no. 9, pp. 1530-1540, Sept. 2000.

L. Fang and L. B. Milstein, "Performance of successive interference cancellation in convolutionally coded multicarrier DS/CDMA systems," *IEEE Transactions on Communications*, vol. 49, no. 12, pp. 2062-2067, Dec. 2001.

1c.   Papers published in non-peer-reviewed journals or in conference proceedings:

L. Fang and L. B. Milstein, "Performance of successive interference cancellation for a multicarrier DS/CDMA system," *IEEE MILCOM 99*, Oct. 31-Nov. 3, 1999, New Jersey, pp. 836-840, Nov. 1999.

L. L. Chong and L. B. Milstein, "Error rate of a multicarrier CDMA system with imperfect channel estimates," *Intlernational Conference on Communications 2000*, vol. 2, pp. 934-938, June 18-22, 2000.

L. Fang and L. B. Milstein, "Analysis of coded successive interference cancellation in multicarrier DS/CDMA systems," *IEEE ISSSTA 2000 Conference*, pp.150-154, Sept. 6-8, 2000.

L. B. Milstein, "A conceptual overview of wideband code division multiple access," *IEEE ISSSTA 2000*, pp. 226-229, Sept. 6-8, 2000.

L Chong and L. B. Milstein, "Comparing DS-CDMA and multicarrier CDMA with imperfect channel estimation," *Proceedings of the 11th IEEE Signal Processing Workshop on Statistical Signal Processing*, Singapore, August 2001, pp. 385-388.

L. Chong and L. B. Milstein, "Convolutionally coded multicarrier DS-CDMA with imperfect channel estimation," *Proceedings of the 39th Annual Allerton Conference on Communication, Control and Computing*, Monticello IL, October 2001.

1d.   Papers presented at meetings, but not published in conference proceedings:

2.   Scientific personnel:

Dr. Laurence B. Milstein
Lucy Chong
Lin Fang

3.   Report of inventions: not applicable.

4.   Scientific progress and accomplishments:

There were two major research thrusts on this grant. The first one concerned the use of a successful interference cancellation (SIC) scheme for a multicarrier (MC) DS/CDMA system. The analytic bit error probabilities for SIC, minimum mean-squared error (MMSE), and matched filter (MF) receivers in correlated Rayleigh fading channels were derived. SIC and MMSE were shown to achieve better performance than the MF; when the number of users was small, SIC provided better performance than did MMSE. The correlation among different subcarriers was also studied; only large subcarrier correlation coefficients resulted in an obvious worsening of performance.

Second, we quantified the performance of SIC in MC DS/CDMA employing either convolutional coding or trellis-coded modulation (TCM). It was shown that TCM out-performed convolutional coding in the presence of severe MAI. It was also shown that TCM with an 8*PSK* constellation performs worse than does TCM with a 16*QAM* constellation. With timing or phase tracking errors, we demonstrated that SIC can still retain a performance advantage over the MF, whereas the improvement gained by TCM 16*QAM* seems to degrade more that 8*PSK* does due to imperfect channel state information.

The SIC described above was actually a soft SIC, meaning one that does not make any hard decisions. We studied another realization of SIC, decision feedback SIC, for coded MC DS/CDMA, where the required fading coefficients were obtained by using pilot symbol assisted SIC with the soft SIC. It was found that the soft SIC was more useful to combat MAI during the initial cancellations, but the pilot symbol assisted SIC outperformed the soft SIC during the latter cancellations. Motivated by the comparison results, we designed a combined system: soft SIC was employed during the initial cancellations, and the system changed to pilot symbol assisted SIC afterwards. The combined SIC scheme was shown to combat the error propagation problem of pilot symbol assisted SIC, and reduce the imperfect cancellation noise as well.

The second major area of research has been the analysis of CDMA systems with four types of diversity under the conditions of imperfect channel estimation. First the standard single carrier CDMA system that makes use of path diversity was analyzed.

A RAKE receiver solved multiple paths in a frequency-selective environment and combined the resolvable paths to improve performance. Second, the performance of a multicarrier DS-CDMA system was derived. In this system, a direct sequence CDMA signal was repeated on multiple parallel non-overlapping subcarriers. This system benefited from frequency diversity. Third, we extended the multicarrier DS-CDMA system to include convolutional coding to study time diversity. Convolutional coding yielded time diversity since each data bit was encoded into multiple coded symbols that were interleaved and transmitted over the channel in different times. Finally, we explored antenna (or space) diversity. A space-time spreading system with dual transmit and dual receive diversity was examined. An equivalent multicarrier space-time spreading system was also proposed and analyzed.

In our analysis, the channel fading information was estimated by using the received pilot signal. The quality of the channel estimates was determined by the length of the estimation period. Given this method for estimation, the probabilities of error for the four systems were derived, taking into account the effects of imperfect estimation. In traditional analysis with perfect fading information, increasing diversity yields monotonically improving performance. However, in systems with estimation errors, increased diversity may not always improve performance. We showed that there is a tradeoff between diversity gain and estimation errors. When the fixed amount of signal energy in a system is divided into more diversity branches, the signal energy available, and thus the signal-to-noise ratio available for estimation, is reduced. This leads to an optimal diversity order that achieves the minimum probability of error. When a system operates at a diversity order higher than the optimal, the probability of error is degraded and also the spectral efficiency is degraded.